

## BOOM GOES THE PRICE: GIANT RESOURCE DISCOVERIES AND REAL EXCHANGE RATE APPRECIATION\*

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We estimate the effect of giant oil and gas discoveries on bilateral real exchange rates. A giant discovery with the value of 10% of a country's GDP appreciates the real exchange rate by 1.5% within ten years following the discovery. The appreciation starts before production begins and the non-traded component of the real exchange rate drives the appreciation. Labour reallocates from the traded goods sector to the non-traded goods sector, leading to changes in labour productivity. These findings provide direct evidence on the channels central to the theories of the Dutch disease and the Balassa–Samuelson effect.

The Dutch disease theory and the Balassa–Samuelson hypothesis predict that a key mechanism through which economies adjust to windfalls or productivity shocks in the traded sector is an appreciation of the real exchange rate (Balassa, 1964; Samuelson, 1964; Corden and Neary, 1982; Eastwood and Venables, 1982; Corden, 1984). Despite the near canonical status of these theories, poor data quality and endogenous measures of resource or productivity shocks have made it challenging to provide robust empirical evidence on the appreciation channel across countries.

In this paper, we estimate the appreciation channel by combining bilateral real exchange rate data with information on giant oil and gas discoveries. By exploiting the uncertainty in the timing of resource discoveries, we overcome the endogeneity problem. By using bilateral data, we obtain a vast increase in the statistical variation available for inference.<sup>1</sup> Our exercise provides direct evidence on the appreciation channel for a wide set of countries. This complements Berka *et al.* (2018) and Chinn and Johnston (1996), who study eurozone countries and 14 OECD countries, respectively.

We find that a country with the median discovery in our sample, 10% of a country's GDP, experiences an appreciation of the real exchange rate of approximately 1.5% over the first ten years following a discovery. By comparison, Rogoff (1996) finds that GDP per capita in a country would have to increase by 4% (relative to the USA) in order to match this degree of appreciation. Berka *et al.* (2018) find that productivity in the traded sector would have to increase by 9% to

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<sup>1</sup> The bilateral real exchange rate has been used by Betts and Kehoe (2006; 2008), Engel (1999) as well as Imbs *et al.* (2005). Much of the remaining literature focuses on real *effective* exchange rates—trade-weighted averages of bilateral real exchange rates (Chen and Rogoff, 2003; Caahin *et al.*, 2004).

generate a similar increase in the real exchange rate.<sup>2</sup> The effect we find is thus quantitatively large.

Economies also adjust to windfalls or traded-sector productivity shocks through the reallocation of labour across sectors. We provide additional direct evidence on the labour-reallocation channel and the associated changes in sectoral labour productivity by focusing on a subsample of 23 OECD countries. Following a giant discovery with the value of 10% of GDP, the employment share in the traded goods sector drops by 0.5 percentage points. Labour productivity increases by 1.8% in the traded sector, and decreases by 0.3% in the non-traded sector. To match these effects, the ratio of natural resources exports to GDP would have to increase by approximately 14%–30%, using the estimates of Kuralbayeva and Stefanski (2013).<sup>3</sup> Again, our estimates are economically large and in line with previous results.

Our contribution is threefold. First, the use of bilateral real exchange rates and unanticipated large resource discoveries allows for better identification of real exchange rate appreciation that follows such discoveries, a mechanism which is central in Dutch disease theories. More generally, we provide evidence for the Balassa–Samuelson effect if we interpret a large discovery as a productivity shock to the tradable sector (Neary, 1988).<sup>4</sup>

Second, focusing on the timing of the discovery allows us to remain agnostic about when the effects on the real exchange rate, labour reallocation and sectoral productivity occur. Arezki *et al.* (2017) and van der Ploeg and Venables (2013) point out that resource discoveries may have effects before production starts as agents borrow in anticipation of higher, future resource income. Engel and West (2005) find that expectation of higher future GDP can lead to nominal exchange rate appreciation. Our estimates show that appreciation and sector reallocation starts soon after the discoveries are made and before production begins, but that there is nonetheless a gradual build-up to the full effect. We emphasise this anticipation effect by constructing and calibrating a standard, dynamic, small-open-economy model. The model reproduces both the magnitudes and the paths of the real exchange rate, labour reallocation and sectoral productivity over the first ten years following a discovery but, possibly due to a lack of modelled frictions, it predicts a somewhat more rapid initial response to discoveries than what we find in the data.

Third, we show that the appreciation is nearly exclusively driven by the non-tradable component of the real exchange rate. This provides strong evidence in favour of the traditional theory of

<sup>2</sup> Rogoff (1996) estimates that a country's price level relative to the USA increases 0.366% as the country's GDP per capita increases 1% relative to the USA ( $0.366 \times 0.04 \approx 0.015$ ). Berka *et al.* (2018) estimate that a 1% increase in the productivity of the traded goods sector leads to a 0.18% appreciation of the real exchange rate ( $0.18 \times 0.09 \approx 0.015$ ).

<sup>3</sup> Kuralbayeva and Stefanski (2013) estimate that as a country's resource-export share rises by 1%, manufacturing employment share decreases by 0.0169 percentage points ( $0.0169 \times 30 \approx 0.5$ ), traded-sector labour productivity rises by 0.097 percent ( $0.097 \times 19 = 1.8$ ) and non-traded-sector labour productivity falls by 0.02 percent ( $0.021 \times 14 = 0.3$ ).

<sup>4</sup> Many other papers have explored this mechanism in the context of the Balassa–Samuelson literature and found that this hypothesis does best in explaining real exchange rates in the longer run (Chinn and Johnston, 1996; Tica and Družić, 2006; Lothian and Taylor, 2008; Chong *et al.*, 2012). For a review of this literature, see Taylor and Taylor (2004). Focusing on the variation in natural resource wealth, a variety of papers have examined Dutch disease predictions empirically by exploring the effects on employment and wages of traded and non-traded sectors (Ismail, 2010; Kuralbayeva and Stefanski, 2013; Smith, 2019), non-resource trade (Harding and Venables, 2016) as well as movements in real exchange rates (Chen and Rogoff, 2003; Caahin *et al.*, 2004; Bjørnland and Thorsrud, 2016). These studies, however, either use endogenous resource measures or do not fully exploit the available cross-country variation for identification and provide quantitatively and qualitatively diverging results. There is also a literature exploiting the within country spatial variation and the reallocation of labour within a country (Beine *et al.*, 2014; Allcott and Keniston, 2017; Aragón *et al.*, 2018). While these papers typically improve on the empirical identification and the data quality, their results have little to add to the discussion on real exchange rate movements and traded-sector employment on the country level.

real exchange rates, where prices of tradable goods are anchored internationally while prices of non-tradable goods are allowed to adjust to local conditions.<sup>5</sup>

## 1. Real Exchange Rates

The appreciation of the real exchange rate is at the core of Dutch disease theories and is often considered to be responsible for the deterioration of the tradable goods sector, i.e., manufacturing. In this section we identify and quantify the cumulative effect of giant discoveries on the real exchange rate and its tradable and non-tradable goods component.

### 1.1. Structure

Consider an economy which consists of mining and utilities, manufacturing as well as a non-resource non-manufacturing sector defined as the sum of agriculture (A), construction (C) and services<sup>6</sup> (S):

$$\text{Total Economy} = \underbrace{\overbrace{A + C + S}^{\text{Non-Resource Economy}}}_{\text{Non Res. Non-Mfg. (N)}} + \underbrace{M}_{\text{Mfg. (T)}} + \underbrace{MU}_{\text{Mining and Utilities}}. \quad (1)$$

Throughout this paper we focus on the non-resource economy only. We treat the manufacturing sector as the traded-goods sector (T) and the non-resource non-manufacturing sector as the non-traded good sector (N).<sup>7</sup>

### 1.2. Exchange Rates

We construct sector-specific price indices using data on one digit ISIC v.3 current and constant sectoral value-added in national currency units from the UN (2014). The IMF's national currency–US exchange rate is used to transform the indices into comparable units. The transformed indices are then used to construct bilateral real exchange rates  $RER_t^{ij}$  between country  $i$  and  $j$  in period  $t$ . Following Engel (1999) as well as Betts and Kehoe (2006; 2008), we decompose these as:

$$\underbrace{\frac{p_{i,t}}{p_{j,t}}}_{RER_t^{ij}} \equiv \underbrace{\left( \frac{p_{i,t}^T}{p_{j,t}^T} \right)}_{RERT_t^{ij}} \times \underbrace{\left( \frac{p_{i,t}/p_{i,t}^T}{p_{j,t}/p_{j,t}^T} \right)}_{RERN_t^{ij}}. \quad (2)$$

Here,  $p_{i,t}$  and  $p_{i,t}^T$  refer to the aggregate and traded-sector price indices in country  $i$  and time  $t$ . The first term on the right-hand side is the bilateral real exchange rate of traded goods,  $RERT_t^{ij}$ . It measures any deviations from the law of one price or differences in the composition of baskets of traded goods across countries. The second term in the above is a ratio of internal relative prices,

<sup>5</sup> Traditional theories of the real exchange rate go back to Cassel (1918) and Pigou (1923). More recently papers by Rebelo and Vegh (1995), Stockman and Tesar (1995) or de Cordoba and Kehoe (2000) examine how sectoral productivity, demand or trade shocks can cause changes to non-traded goods prices, which then drive fluctuations in real exchange rates.

<sup>6</sup> Services are defined as the sum of transportation, storage, communication, wholesale, retail, restaurants, hotels and other services.

<sup>7</sup> Altering the sectoral specification by moving agriculture to the traded sector or considering only services as the non-traded sector does not affect our results.

denoted by  $RERN_t^{ij}$ . As is emphasised by Betts and Kehoe (2008), we could write this as:

$$RERN_t^{ij} = \frac{p_{i,t}(p_{i,t}^T, p_{i,t}^N)/p_{i,t}^T}{p_{j,t}(p_{j,t}^T, p_{j,t}^N)/p_{j,t}^T}, \quad (3)$$

where  $p_{i,t}^N$  is a price index for non-traded goods in country  $i$ , and we make explicit the dependence of  $p_{i,t}$  on the indices of both traded and non-traded goods. The functional form of  $RERN_t^{ij}$  however depends on how statistical offices in each country construct aggregate price indices.<sup>8</sup> To circumvent the need to assume a functional form or to measure the prices of non-traded goods, we follow Betts and Kehoe (2008) and use the equational form in (2) to calculate  $RERN_t^{ij}$ . Thus, we can decompose the real exchange rate into the tradable and non-tradable components just from data on traded goods price indices and aggregate price indices. Our sample covers  $N = 172$  countries over the period 1970–2013. Not double-counting country pairs, the number of unique observations per year is  $\frac{N^2 - N}{2} = 14,706$ . Using all available information gives us 12,536 unique country pairs and a total of 383,934 observations. See Table A.1 in the Online Appendix for a snapshot of the data.

### 1.3. Giant Oil and Gas Discoveries

Information on the timing of individual giant oil and gas discoveries, as provided by Horn (2011), is essential for our study for two reasons. First, we need the timing of discoveries since we are interested in understanding Dutch disease dynamics and what happens to outcome variables between a discovery and the start of production. Second, the difficulty in anticipating discoveries places the timing of these discoveries at the centre of our identification strategy. We follow Lei and Michaels (2014) and Arezki *et al.* (2017) in arguing that discoveries are plausibly exogenous due to the uncertainty surrounding exploration and future technology developments, once we control for country and year fixed effects and previous discoveries.<sup>9</sup> Countries and exploration companies are unlikely to make such discoveries, as only about 2% of the exploration wells in a global data set starting in 1965 turned into giant discoveries (Toews and Vezina, 2017). Consequently, predicting the exact timing of a giant oil discovery is difficult, even for the operating companies. Figure 1(a) presents the relationship between the real price of oil and the total number of giant discoveries. Note that the number of discoveries is uncorrelated with the real price of oil, with a correlation coefficient below 0.02 and a  $p$ -value of 0.9, increasing the confidence in our identification strategy.

Our main measure of treatment is the net present values of giant oil and gas discoveries relative to GDP in country  $i$  and period  $t$ ,  $d_t^i$ , which we received from Arezki *et al.* (2017). The raw data on discoveries contains information on the timing, the location and the estimated total ultimately recoverable amount of oil and gas (Horn, 2011). To calculate the net present value of each discovery at the date of discovery, Arezki *et al.* (2017) combine the data from Horn (2011) with a generic approximated oil production profile, the nominal oil price at the date of discovery and a country specific interests rate to discount future revenues. They normalise the resulting

<sup>8</sup> For example, if we were to assume that  $p_{i,t}(p_{i,t}^T, p_{i,t}^N) = (p_{i,t}^T)^{\gamma_i} (p_{i,t}^N)^{1-\gamma_i}$ , then  $RERN_t^{ij}$  is an explicit function of relative internal prices,  $RERN_t^{ij} = \frac{(p_{i,t}^N/p_{i,t}^T)^{1-\gamma_i}}{(p_{j,t}^N/p_{j,t}^T)^{1-\gamma_j}}$ .

<sup>9</sup> In contrast, more common measures of endowments such as resource wealth or exports are seen as endogenous. Brunnschweiler and Bulte (2008) and van der Ploeg and Poelhekke (2010) discuss this endogeneity in the context of the resource curse. Cust and Harding (forthcoming) focus on the quality of institutions as a source of endogeneity.



value on nominal GDP measured at the date of discovery.<sup>10</sup> The calculated values are presented in Figure 1(b). Between 1970 and 2013, 302 giant discoveries were made in 56 countries. The average and median size of discoveries is 67% and 10% of GDP, respectively.

We use  $\delta_t^i = 1 + d_t^i$  as a simple monotonic transformation of the discovery measure  $d$  above and define a bilateral measure of discoveries:

$$D_t^{ij} \equiv \log \left( \frac{\delta_t^i}{\delta_t^j} \right). \quad (4)$$

$D$  is robust to zeros in the denominator and symmetric in that a discovery in country  $i$  and country  $j$  have the same quantitative impact, but opposite signs:  $\frac{\partial D_t^{ij}}{\partial \log(\delta_t^i)} = -\frac{\partial D_t^{ij}}{\partial \log(\delta_t^j)} = 1$ .

#### 1.4. Estimation Strategy

We estimate the following specification:

$$gX_t^{ij} = \sum_{k=-5}^{10} \beta_k D_{t-k}^{ij} + \eta^{ij} + \rho_t + \varepsilon_t^{ij}. \quad (5)$$

Our dependent variable is the growth in the bilateral real exchange rate which we define as the change in the natural log of the real exchange rate and its components:  $gX_t^{ij} \equiv \log(X_t^{ij}) - \log(X_{t-1}^{ij})$ , where  $X = RER, RERT, RERN$ . Country-pair and time fixed effects are represented by  $\eta^{ij}$  and  $\rho_t$  respectively. The latter capture global shocks. Since our dependent variables are growth rates, country-pair fixed effects capture trends in relative prices between the two countries. Thus, we study the impact of giant discoveries on deviations from country-pair specific trends. The  $\beta_k$  terms represent the year-to-year growth effect of discoveries  $k$  periods after the discovery. We are interested in the cumulative effect of a discovery on the real exchange rate  $k$  periods after a discovery in period  $t$ , which is the sum of the year-to-year growth effects for the years  $t$  to  $t + k$ . Thus, we estimate the cumulative effect of an oil discovery on the real exchange rate via summation,  $\Omega_k = \sum_{j=1}^k \beta_j$ , and use these to construct 95% and 90% confidence bands. Symmetrically, we present the cumulative estimates by adding up the  $\beta_k$ 's of the leads:  $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$ .<sup>11</sup> The country-pair specific error,  $\varepsilon_t^{ij}$ , is allowed to arbitrarily correlate with errors of other bilateral pairs containing either country  $i$  or country  $j$  (two-way clustering).

#### 1.5. Results

The main results are displayed in the three charts of Figure 2. The solid lines show the cumulative impulse response  $\Omega_{t \in [1, 10]}$  to a giant discovery, while the dashed and the dotted lines indicate 90% and 95% confidence intervals. The first chart depicts the cumulative response of the real exchange rate to a giant discovery. In the second and third charts we decompose the effect on the real exchange rate into the effect on the tradable and the non-tradable component, respectively.

<sup>10</sup> See equation (11) in Arezki *et al.* (2017) for the exact formula of the measure we use.

<sup>11</sup> Note that this allows us to test for diverging pre-trends between the treatment and the control group before the discovery. Diverging pre-trends would indicate that we should be careful with the causal interpretation of our results. However, as will be shown throughout the paper, the pre-trend development of all outcomes in countries which are about to have a discovery is statically indistinguishable from the pre-trend developments in the control group.



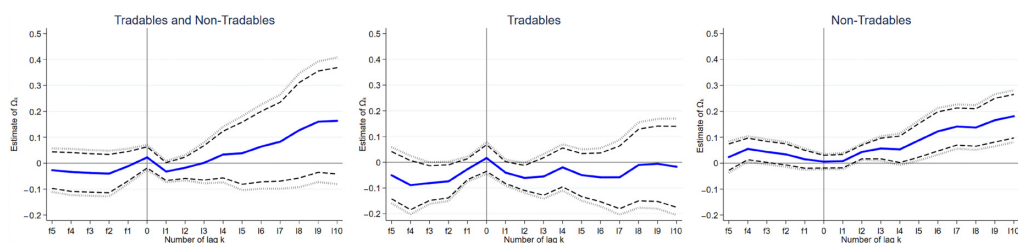


Fig. 2. *Cumulative Effect of Large Discoveries on the Real Exchange for All Countries.*

*Notes:* All results include country-pair fixed effects and year fixed effects. The left-hand side (LHS) variable is either the change in the logged real exchange rate between two countries, the change in the tradable or the change in the non-tradable component of the logged real exchange rate. The solid line is the sum of year-to-year growth effects for the years  $t$  to  $t + k$ . The cumulative effect is calculated by adding  $\beta_k$ 's which are estimated in equation (5):  $\Omega_k = \sum_{j=1}^k \beta_j$ . Symmetrically, we present the cumulative estimates by adding up the  $\beta_k$ 's of the leads:  $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$ . The dashed and the dotted lines represent the 90% and the 95% confidence intervals. To calculate the confidence intervals we employ a two-way clustering which allows the errors to correlate arbitrarily with errors of other bilateral pairs containing one of the countries within the pair.

First of all, note that in the periods before the discoveries, indicated by the vertical line, there is no apparent and statistically significant difference in price changes in the countries which are about to be treated relative to the control group. This is important since the implicit assumption allowing us to interpret our results as causal is that prices in the treated and control group follow a similar trend in the absence of a discovery. In case of the prices of tradable goods we do not observe any significant divergence in prices following a discovery. Thus, we conclude that consistent with standard economic theory, prices of tradable goods remain unaffected by country-specific shocks. On the other hand, the third chart shows that discoveries positively affect the non-tradable goods component of the real exchange rate. The results imply that ten years after a median-sized discovery (10% of GDP) the non-tradable goods component of the real exchange rate increases by 1.7%.<sup>12</sup> Also note that the prices of non-tradable goods component start increasing immediately following the discovery and are already significantly higher in the treated group by the time production typically starts, four to six years following the discovery (Arezki *et al.*, 2017). This is in line with the idea that forward-looking agents may borrow and spend in anticipation of a higher future resource income before production starts, i.e., Dutch disease dynamics.

Consistent with the discussion above we find that the real exchange rate starts appreciating following a discovery. And while the cumulative effect on the real exchange rate is measured imprecisely we find that the exchange rate appreciates by 1.6% within ten years following a median-sized discovery. The magnitude of the real exchange rate appreciation is nearly identical to the appreciation of the non-tradable goods component of the real exchange rate. By comparing the three charts, it is apparent that the appreciation of the real exchange rate is entirely driven by its non-tradable goods component. Note that the large confidence interval originates in the imprecise estimation of the effect on the prices of tradable goods. This is consistent with the well-documented results that most of the variance in the bilateral exchange rates is attributable to fluctuations in the real exchange rate of traded goods (Engel, 1999).

<sup>12</sup> From chart 3 of Figure 2,  $\Omega_{10} = \sum_{j=1}^{10} \beta_j = 0.18$ . The impact of a median discovery is thus  $0.017 \approx 0.18 \times \log\left(\frac{1+0.1}{1}\right)$ .

### 1.6. *Robustness*

In Online Appendix A we present a battery of robustness tests for our main results. First, we reproduce Figure 2 by adjusting our measure to taxation. In particular, we use tax data from Wood MacKenzie to estimate country-specific taxes, using total government take as our measure for the amount of taxes collected, to adjust the measure provided to us by Arezki *et al.* (2017) in attempt to control for differences in the proportion of the value of discoveries that accrue to government. The results are slightly larger but do not differ significantly from our baseline result as shown in Figure A.1. Second, instead of using the GDP adjusted measure of discoveries we reproduce our main results using time dummies. This allows us to address potential endogeneity concerns and measurement issues with the discovery measure by focusing exclusively on the timing of discoveries. The results are presented in Figure A.2 for the full sample and for the OECD subsample defined in the next section. Third, to examine whether our results are spurious, we conduct a randomisation test by randomly reallocating discoveries across countries and time. The distribution of point estimates from re-estimating equation (5) with the artificial data is symmetric and centred at zero, indicating that our econometric model is unlikely to produce spurious results (see Figure A.3). Fourth, we show that the results are robust to changing the treatment and control group by varying the number of lags and by reducing the sample to countries which had at least one giant discovery since 1970 (see Figures A.4 and A.5). Fifth, in Figure A.6 we control for cumulated past discoveries to account for potential path-dependence in discoveries. Sixth, we drop the top and the bottom 1% of the dependent variable to account for outliers (see Figure A.7). Seventh, to ensure that our results are not sensitive to specific sector classifications, we use alternative definitions of tradable and non-tradable goods and present the results in Figures A.8 and A.9. In all the robustness tests presented in Figures A.1–A.9, the results remain unaffected. Eighth, following Betts and Kehoe (2008), we use producer prices as alternative price measures. The results are presented in Figure A.10. The magnitudes remain in line with our baseline specification, but the error bands are wider in this smaller sample. Finally, we also estimate the effect of oil discoveries on unilateral real effective exchange rates confirming our results (see Figure A.11).

## 2. Labour Reallocation and Productivity

Economies adjust to resource windfalls not only through price changes, but also through the reallocation of factors across sectors. In this section we identify and quantify the effect of giant discoveries on the reallocation of labour as well as the associated changes in labour productivity for a subsample of countries.

### 2.1. *OECD Sample*

To explore the reallocation channel we focus on countries that were OECD members by 1973.<sup>13</sup> We restrict our analysis to these countries since our identification strategy relies on time-series variation which requires comparable, high-quality data going back to the beginning of our sample. Countries in this sample had the capacity and an explicit agenda to collect comparable sector-level

<sup>13</sup> The sample consists of the following OECD countries: Australia, Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, UK and USA.



data as early as 1970 (den Butter, 2007). Finally, it is important to emphasise that approximately 25% of the 302 giant discoveries between 1970 and 2013 were made by nine countries in this sample leaving us with enough variation for identification.

## 2.2. Employment Data

We obtain sectoral employment data for 1970 to 2013 from the ILOSTAT online database, which is based on population censuses, national labour force surveys as well as official estimates.<sup>14</sup> We use these data to compute employment shares of the traded and non-traded sector in each country. Using all available information gives us data on 23 countries up to 43 years and a total of 878 observations.

## 2.3. Productivity Data

We construct data on sectoral labour productivity for 1970 to 2013. We obtain one digit ISIC v.3 sectoral value-added data from the UN in constant (2005) US dollars. Following the procedure outlined in Kuralbayeva and Stefanski (2013), we convert this into constant (2005) international (or PPP) dollars using country-sector specific price-level data from the World Bank's 2005 International Comparison Program (ICP). Finally, we calculate value added per worker in constant (2005) international dollars in the traded and non-traded sectors by combining this data with the employment data described above. Using all available information gives us 878 observations. See Table A.2 in the Online Appendix for descriptive statistics.

## 2.4. Estimation Strategy

As before, our identification strategy relies on the timing of giant discoveries and we emphasise the exogeneity of the timing by providing five year-long pre-trends. However, whereas before our focus was on price difference across countries over time, here we focus on sector level differences within the same country and, thus, we estimate the following specification:

$$gX_t^i = \sum_{k=-5}^{10} \beta_k \log(\delta)_{t-k}^i + \eta^i + \rho_t + T_t^i + \varepsilon_t^i. \quad (6)$$

Here our LHS variable,  $gX_t^i$ , is a placeholder for the employment share changes in the tradable sector, labour productivity growth in the tradable sector or labour productivity growth in the non-tradable goods sector in country  $i$ .<sup>15</sup> Our measure of discoveries is now the unilateral, monotonic transformation of the discovery measure  $d$ —discussed in the previous section. Country fixed effects and time fixed effects are captured by  $\eta^i$  and  $\rho_t$  respectively. In our preferred specification we also add a country specific linear trend,  $T_t^i$ , to capture the systematic evolution of sectoral employment and productivity associated with structural transformation (see for example Herrendorf *et al.*, 2014 or Lagakos and Waugh, 2013).<sup>16</sup> As before, the  $\beta_k$  terms represent the semi-elasticities of discoveries  $k$  periods away from the discovery which we add up according

<sup>14</sup> We combine the ISIC revisions 2, 3 and 4 of the employment data. Missing data is supplemented using information from the Groningen Growth and Development Centre 10-sector database.

<sup>15</sup> We normalise labour productivity in the tradable and non-tradable sectors by average labour productivity within the same country and period to account for country-level changes in labour productivity.

<sup>16</sup> See Figure A.12 in the Online Appendix for the results without the trend.

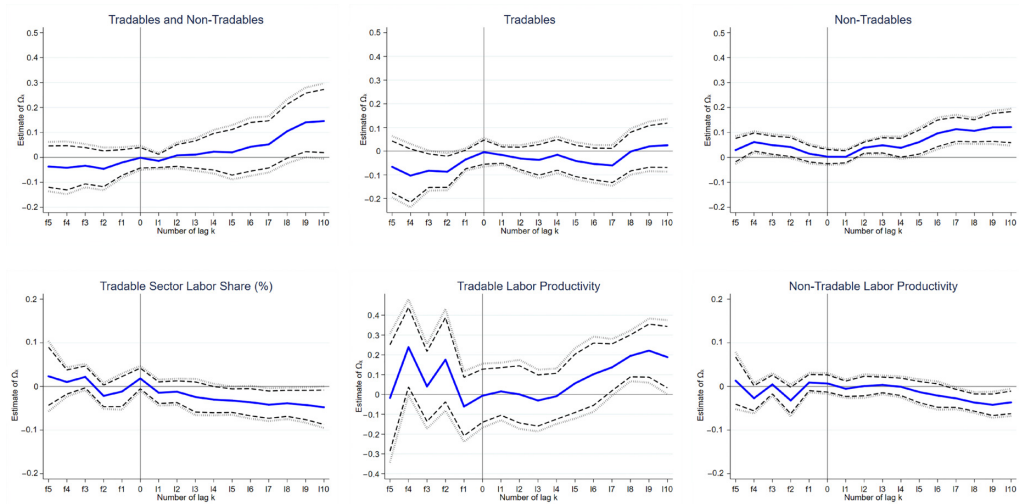


Fig. 3. Cumulative Effect of Large Discoveries on the Real Exchange, Labour Shares and Productivities in OECD Subsample.

*Notes:* Results are based on the subsample of OECD countries defined in the text. The LHS variable in the *first row* is either the change in the logged real exchange rate between two countries, the change in the tradable or the change in the non-tradable component of the logged real exchange rate. All results include country-pair fixed effects and year fixed effects. The LHS variable in the *second row* is either the change in the traded sector labour share, changes in traded sector labour productivity or changes in the non-traded sector labour productivity. All results include country fixed effects, year fixed effects and a country-specific linear trend. (See Figure A.12 in the Online Appendix for the results without the trend.) The solid line is the sum of year-to-year growth effects for the years  $t$  to  $t+k$ . The cumulative effect is calculated by adding  $\beta_k$ 's which are estimated in equation (6):  $\Omega_k = \sum_{j=0}^k \beta_j$ . Symmetrically, we present the cumulative estimates by adding up the  $\beta_k$ 's of the leads:  $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$ . The dashed and the dotted lines represent the 90% and the 95% confidence intervals. To calculate the confidence intervals we employ a two-way clustering in the *first row*. This allows the errors to correlate arbitrarily with errors of other bilateral pairs containing one of the countries within the pair. We cluster the standard errors on the country level in the *second row*.

to the following formula  $\Omega_k = \sum_{j=1}^k \beta_j$  for the lags and according to the following formula  $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$  for the leads. The country-specific error is  $\varepsilon_t^i$  and standard errors are clustered on the country level.

## 2.5. Results

The results are presented in Figure 3. The first row emphasises that our previous findings with respect to the bilateral real exchange rates remain quantitatively and qualitatively unchanged in this particular subsample: a discovery with the value of 10% of a country's GDP leads to a 1.5% appreciation of the real exchange rate.<sup>17</sup> Furthermore, unlike in the full sample, the result on the real exchange rate is significant at the 5% level.

Next, we turn to the estimation of employment and productivity effects of giant oil and gas discoveries. At the core of Dutch disease theories is the idea that an increase in income leads to

<sup>17</sup> The estimation consists of all bilateral combinations of countries which includes at least one of the 23 OECD countries.

Table 1. *Summary of Responses to Giant Resource Discovery (Equivalent to 10% of GDP) After Ten Years.*

Responses	RER	RERT	RERN	Mfg. emp. sh.	Mfg. prod.	Non-mfg. prod.
Data (full)	1.6%	−0.1%	1.7%	−	−	−
Data (OECD)	1.5%	0.3%	1.2%	−0.45pp	1.8%	−0.3%
Model	1.4%	0%	1.4%	−0.70pp	1.4%	−0.3%

Notes: The model estimates are well within the 90% confidence bounds of our estimates.

higher spending and a reallocation of labour from the traded to the non-traded sector. In the first chart of the second row we provide evidence for the presence of this mechanism by exploring the effect on the employment share in the traded sector (see equation (1) for the definition). Changes in employment shares before the discovery do not differ significantly between the treated group and the control group. But following the discovery, labour shares in the tradable goods sector decreases relative to the control group. In particular, a median discovery decreases the employment share in the traded sector by 0.45 percentage points. Since the average country employs 14% of its labour force in the traded sector, our results suggest that traded-sector employment drops by 4% in the first ten years following a median discovery. Also note that by the time production typically starts approximately five years following the discovery, more than 50% of the ten-year cumulative effect has already occurred. This, once again, indicates that Dutch disease dynamics begin to operate well before production starts. We also report the effect of discoveries on labour productivity in the respective sectors in the two bottom-right charts. We focus on labour productivity both because models of Dutch disease offer stark predictions with respect to this measure (see Kuralbayeva and Stefanski, 2013 or the model in Online Appendix B) but also because—lacking sufficiently high-quality wage data going back to 1970—under minimal assumptions these measures can be interpreted as constant-price sectoral wages.<sup>18</sup> A median discovery increases labour productivity in the traded sector by 1.8% and decreases it in the non-traded sector by 0.3%.

Finally, to address potential endogeneity and measurement concerns related to our measurement of discoveries, we reproduce the results by replacing our discovery measure with time dummies. Results are qualitatively similar and are presented in Figure A.13.

3. Theory

To put our estimates in perspective we summarise the empirical results of the previous section in rows 1 and 2 of Table 1 and compare them to the theoretical predictions of a calibrated model in the bottom row. These theoretical results are based on a simple, small-open-economy model calibrated to the experience of Canada—arguably a small, open and resource-rich country. The model, presented in Online Appendix B, is designed to capture the main mechanisms of the original model by Corden and Neary (1982). The real exchange rate is entirely driven by changes in the prices of non-tradable goods, labour can move freely to equalise the marginal revenue products across sectors and capital is sector-specific. In contrast to the original model we allow for forward-looking behaviour and borrowing to capture Dutch disease dynamics which have

<sup>18</sup> According to standard theory, wages, measured in units of sectoral output, are equal to a worker's marginal productivity and—under a Cobb–Douglas production function—are also proportional to average labour productivity (output per worker). See the illustrative example in Online Appendix B for details.

been emphasised by van der Ploeg and Venables (2013). In that setting, a discovery may trigger an increase in spending long before production starts. Intuitively, agents expecting future windfalls borrow from abroad to smooth consumption and hence increase their spending on tradable and non-tradable goods. While higher demand for tradable goods can be satiated by imports from abroad, more workers must be employed in the non-tradable sector to meet the higher demand for locally produced non-tradable goods. In order for this to happen, prices of non-tradable goods rise, increasing the wages in the non-tradable sector and pulling workers out of the tradable sector into the non-tradable sector. The reallocation of workers in the presence of a fixed factor leads to lower labour productivity in the non-traded sector and higher labour productivity in the traded sector. Notice that the response to the discovery in our model is not instantaneous, since there is a debt-elastic interest rate that increases with borrowing. This prevents agents from perfectly smoothing expected future revenues. We find that our empirical estimates match the predictions of the model very well, except that the instantaneous adjustments at the time of discovery are more muted in the data than in the model.

#### 4. Conclusion

We provide robust evidence for an appreciation of the real exchange rate in response to a large oil or gas discovery. A discovery equivalent in value to 10% of a country's GDP causes the real exchange rate to appreciate by 1.5% within ten years. Consistent with traditional theories of exchange rates, we find that the appreciation is almost exclusively driven by the non-traded component of the real exchange rate. We also provide evidence for the reallocation of labour from the traded to the non-traded sector. In particular, we find that following a median discovery, half a percentage point of the total labour force reallocates from the tradable to the non-tradable goods sector within ten years. Finally, we provide additional evidence on changes in sectoral labour productivity associated with this reallocation. Following a median discovery, labour productivity rises by 1.8% in the traded sector and decreases by 0.3% in the non-traded sector. Importantly, the empirical findings match very well with the predictions of a standard, small-open-economy model of exchange rates. This paper thus provides the first direct evidence of the key appreciation and reallocation channels central to both the Dutch disease and the Balassa–Samuelson literature, in the framework of a quasi-natural experiment.

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Additional Supporting Information may be found in the online version of this article:

#### **Online Appendix** **Replication Package**

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